Int. J. Chem. Sci.: 14(2), 2016, 1197-1210
ISSN 0972-768X
www.sadgurupublications.com

FAILURE ANALYSIS OF SOLID CARBIDE CUTTING TOOL USED IN MILLING OPERATION

V. GNANASEKARAN[a], J. EKANTHAMOORTHY[a] and K. SENTHILKUMAR[b]

[a]Assistant Professor, Department of Mechanical Engineering, Karpaga Vinayaga College of Engineering & Technology, CHENNAI (T.N.) INDIA
[b]Associate Professor, Department of Mechanical Engineering, Karpaga Vinayaga College of Engineering & Technology, CHENNAI (T.N.) INDIA

ABSTRACT

Cutting tools are subjected to frequent failures during machining. Such failures are due to chip formation, wear and chattering. The main objective of this work is to find optimal cutting parameters for enhancing the tool life of the chatter free end mill cutter (ISCAR) while machining MDN 321 steel and to establish process failure mode and effect analysis (P-FMEA) for the end milling process. This project was conducted in Precision Machining Centre (PMC), L & T Coimbatore. Preliminary studies were done to find out the frequently occurring cutting tool failure by using standard quality tools. Pareto chart and fishbone was constructed for the end milling process. Based on the common failures of the milling cutter a Design of experiment (DOE) was formulated to find out the optimal cutting conditions for tool wear and surface roughness. Based on the fishbone diagram, risk priority number (RPN) was calculated for each mode of failure. The preventive steps and procedures were suggested to the failures with high RPN. From the preliminary studies it has been found out that 34.6% of failure is occurring in ø12 chatter free end mill cutter. The optimized cutting condition for tool wear are cutting speed of 250 m/min and axial depth of cut 0.25 or 0.50 mm. The cutting conditions for better surface roughness are cutting speed of 250 m/min, axial depth of cut 0.25 mm, and feed rate 0.10 mm/rev. From the analysis, it has been found out that chip packing due to excess cutting depth has the highest risk priority number. This can be reduced by varying the feed rate and spindle speed.

Key words: MDN 321, DOE, RPN, Tool wear, Surface roughness, Chip packing.

INTRODUCTION

Some of the commonly occurring cutting tool failures in machining industries are excessive current or power consumption, excessive vibration or abnormal sound, total

*Author for correspondence; E-mail: gnanampsg1066@gmail.com, senthilmechhod@gmail.com, jekanthamoorthy@gmail.com

breakage of the tool, rapid worsening of surface finish and adverse chip formation. For investigating such tool failures macroscopic analysis, chemical testing, hardness testing, metallographic investigation can be carried out. For resisting early tool failures cutting tool material must have properties such as high mechanical strength, compressive strength, tensile strength, fracture toughness, high hardness, chemical inertness against work material, resistance to adhesion and diffusion, high heat resistance, high stiffness, manufacturability, availability and low cost. Various failure mechanisms are discussed as follows. Gradual wear of cutting tool at its flanks and rake surface is inevitable and cannot be prevented but can be slowed down only to enhance the service life of the tool. Crater wear is a tool wear in which contact with chips erodes the rake surface. When hard rough surface slides across the softer surface abrasion occurs. Chipping occurs as a result of overload of mechanical tensile stress. Tool wear can be measured by different methods such as grooving and indentation method, optical microscope fitted with micrometer, Scanning electron microscope (SEM).

Literature survey

In order to know about the various cutting tool failures and to overcome them literature survey was carried out. The details of the papers are presented here. Vinod Kumar et al.[1], in his paper presents an FEM analysis conducted for optimally designing end mill cutters through verifying the cutting tool forces and stresses for milling Titanium alloy Ti-6Al-4V. Considering the lowest tool forces the cutting tool parameters are taken and optimal design of end mill is decided for different sizes. Then the 3D CAD models of the end mills are developed and used for Finite Element Method to verify the cutting forces for milling Ti-6Al-4V. The cutting tool forces, stress, strain concentration (s), tool wear, and temperature of the cutting tool with the different geometric shapes are simulated considering Ti-6Al-4V as work piece material. Finally, the simulated and theoretical values are compared and the optimal design of cutting tool for different sizes are validated. The present approach considers to improve the quality of machining surface and tool life with effects of the various parameters

Pravin Kumar S. et al.[2] in their work on process failure mode effect and analysis of End Milling process performed a series of end milling process on several work pieces and the potential failure and defects in the work piece and the tool are studied. These are categorized based on FMEA, risk priority numbers are assigned to each one and by multiplying the ratings of occurrence, severity and detection. Finally the most risky failure according to the RPM numbers is found and the cause and effects along with the preventive measures are tabulated.

Miroslav Zetek et al.[3] in his work on increasing cutting tool life while Machining of Inconel 718 inferred that the cutting edge is stressed by high temperature and pressure in a small area. So it is important to use fluids with high pressure and a very accurate and high quality cutting wedge. When cutting inserts are used we can do this by special internal cooling systems and special inserts. Main aim for the increasing of the cutting tool life is in the cutting edge micro geometry which is designed by special processes after grinding or after deposition of the thin layer. When the special edge modification is used the cutting edge has high quality, an identifiable edge radius and better roughness on the back and rake area and identifiable K factor. For the good deposition of the thin layer and longer tool life of a monolithic cutting tool it is important to have an optimal value of the radius.

J Paulo Davim et al.[4] in his work has carried out experiments using ceramic cutting tools, composed approximately 70% of Al_2O_3 and 30% of TiC, in surface finish operation on cold work tool steel D2 (AISI) heat treated to a hardness of 60 HRC. They made a plan o experiments with prefixed cutting parameters in tool steel workpieces. The results shows with appropriate cutting parameters it is possible to obtain a surface roughness less tha 0.8 μm that allows to eliminate cylindrical grinding operations.

Vikas B. Magdum et al.[5] in his study on optimization and evaluation of machining parameters for turning on EN8 steel on Lathe machine has investigated the use of tool materials and process parameters for machining forces for selected parameter range and estimation of optimum performance characteristic is done. HE also developed a methodology for optimization of cutting forces and machining parameters.

Bala Murugan Gopalsamy et al.[6] in their paper has applied Taguchi method to find optimum process parameters for end milling while hard machining of hardened steel. A L18 array, signal-to-noise ratio and analysis of variance (ANOVA) are applied to study performance characteristics of machining parameters (cutting speed, fee, depth of cut and width of cut) with consideration of surface finish and tool life. Results obtained by Taguchi method match closely with ANOVA cutting speed is most influencing parameter. Multiple regression equations are formulated for estimating predicted values of surface roughness and tool wear.

S. Hasan et al.[7] in his research has analysed the optimum cutting conditions to get lowest surface roughness in turning SCM 440 alloy steel. Taguchi method was adopted and it was found out that the depth of cut has significant role in producing lower surface roughness followed by fee. The cutting speed has lesser role on surface roughness from the tests.

R. K. Suresh et al.[8] in their work envisages the optimal setting of process parameters, which influences the surface roughness during the machining operation of En41B alloy steel with cermet tool. From the results the feed and speed are identified as the most influential process parameters on work piece surface roughness.

Ali Riza Motorcu[9] in his work on optimization of machining parameter for surface roughness of AISI 8660 hardened alloy steel has found out the effective cutting parameters and nose radius on the surface roughness. The results indicate that the feed is the dominant factor followed by depth of cut and tools nose radius. However, the cutting speed showed an insignificant effect.

Problem definition

From the data collected for Precision Machining Centre it has been inferred that cutting tools are subjected to frequent failure during machining of MDN 321 steel jobs. During milling operation, ø12 chatter free end mill cutting tool is subjected to failure due to wear and total breakage. Cumulatively about 63.6% of ø12 chatter free end mill cutter failure is due to wear and total breakage. Further there are various failure modes occurring in milling operation. In order to prevent defects, enhancing safety and increasing customer satisfaction measures should be taken.

Methodology

The methodology to be followed was shown in the flowchart.

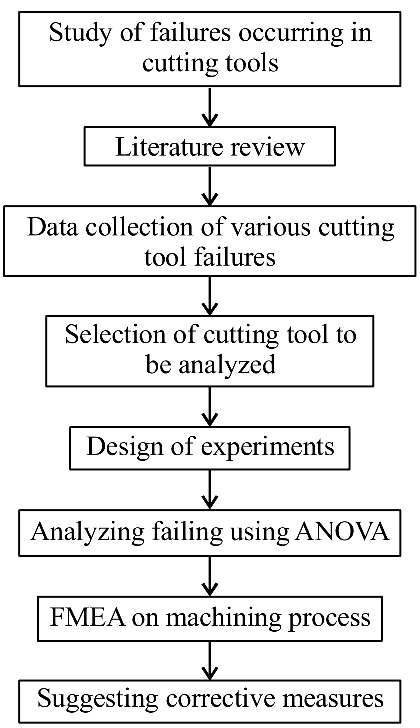


Fig. 1: Methodology

Data collection for various failures occurring in the machine shop was carried out to know about the most frequently occurring cutting tool failure. Once the cutting tool to be analyzed is identified, design of experiments will be conducted to find out the optimum cutting parameters for the particular operation. Cutting parameters will be analyzed further using ANOVA and finally FMEA will be established for the operation under study.

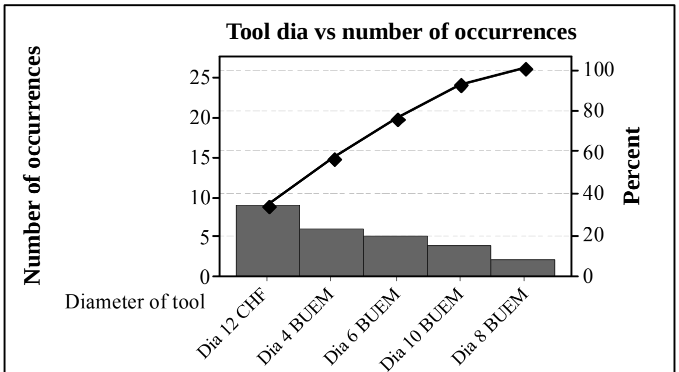
Data collection

For a time duration of one month data are collected for cutting tool failure. For more accuracy past six months data are collected for cutting tool failure.

Pareto diagram

Pareto diagram is a tool that arranges items in the order of the magnitude of their contribution, thereby identifying a few items exerting maximum influence. This tool is used in quality improvement for prioritizing projects for improvement, identifying products on which most complaints are received, identifying the nature of complaints occurring most often, identifying most frequent causes for rejections.

From the Fig. 2 it can be inferred that ø 12 chatter free end mill cutter is the most occurred failure among cutting tools. About 34.6% of failure is in ø 12 chatter free end mill cutter. Therefore, failure analysis will be done for ø 12 chatter free end mill cutter. From the Fig. 3 it can be inferred that 36.4% of failure is due to wear and 27.3% of failure is due to total breakage of the cutting tool. The job handled by ø 12 chatter free end mill cutter is shown in the Fig. 4. It can be inferred that similar kind of failure is occurred in all the four parts.



Number of occurrences	9	6	5	4	2
Percent	34.6	23.1	19.2	15.4	7.7
Cum %	34.6	57.7	76.9	92.3	100.0

Fig. 2: Pareto chart for overall cutting tool failure

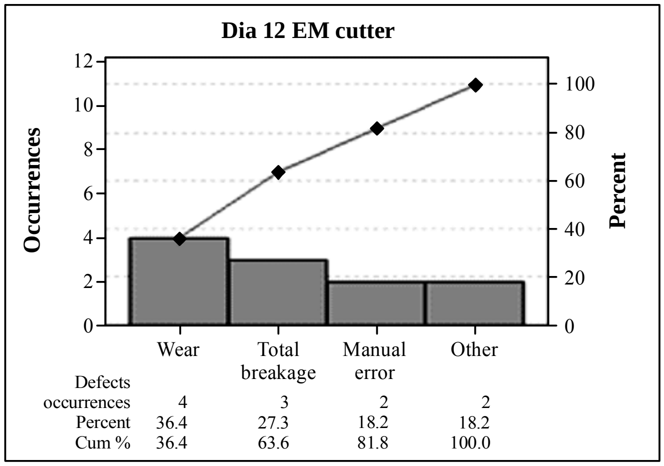


Fig. 3: Pareto chart for failures in ø 12 end mill cutter

Fig. 4: Job in which failure occurs

Fig. 5: Broken chatter free end mill cutter

Apart from wear at the edges the cutting tools are also suffering total breakage while machining. Therefore the problem is very clearly defined and steps are then carried out to sort out the problems occurring while machining MDN321 steel job using ø 12 chatter free end mill cutter shown in Fig. 5.

A cause and effect diagram is a tool that shows systematic relationship between a result or a symptom or an effect and its possible causes. It is an effective tool to systematically generate ideas about causes for problems and to present these in a structured form. Fishbone diagram for ø 12 chatter free end mill cutter was shown in the Fig. 5. The causes and effects are classified based on measurements, material, personnel, environment, methods and machines. All the causes and effects which are identified will be useful for establishing process failure mode and effect analysis.

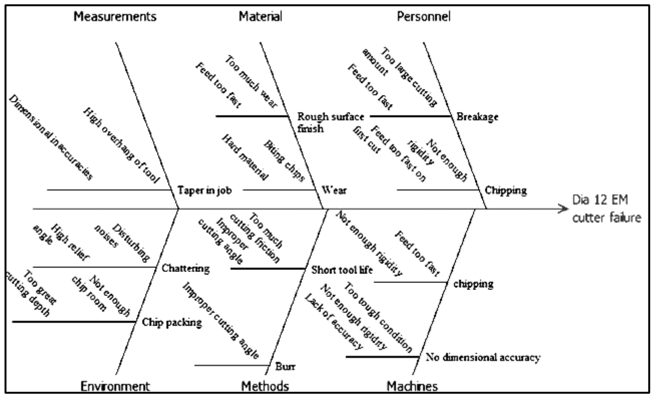


Fig. 6: Fishbone diagram for ø 12 end mill cutter failure

Design of experiments

This experimental work was to investigate the effects of cutting parameters on tool wear and surface roughness. In order for this cutting speed, feed rate and depth of cut were chosen as process parameters. The work material was MDN 320 steel. Chemical composition of the work material is given in Table 1.

Table 1: Chemical composition of mdn 321 steel

C	Si	Mn	Cr	Ni	S	P	Ti	Fe
0.058	0.59	1.19	18.48	10.35	0.009	0.02	0.59	Balance

Selection of the design

The aim of the experiments was to analyze the effect of cutting parameters on the tool wear and surface roughness. The experiments were planned using Taguchi's orthogonal array in the design of experiments which help in reducing the number of experiments. The experiments were conducted according to a three level L27(3^3) orthogonal array. The cutting parameters identified were cutting speed, depth of cut and feed as shown in Table 2.

Table 2: Chemical composition of MDN 321 steel

Machining parameters	Unit	Level 1	Level 2	Level 3
Cutting speed	m/min	150	200	250
Feed	mm/tooth	0.05	0.1	0.2
Depth of cut	mm	0.05	0.1	0..2

Table 3: Designs of experiments

	Machining parameters			Tool wear (mm)	Ra (μm)
	V (m/min)	F (mm/rev)	D (mm)		
1	150	0.05	0.05	0.23	0.778
2	150	0.05	0.1	0.25	1.660
3	150	0.05	0.2	0.28	0.991
4	150	0.1	0.05	0.20	0.920
5	150	0.1	0.1	0.26	2.812
6	150	0.1	0.2	0.11	2.430
7	150	0.2	0.05	0.22	1.450
8	150	0.2	0.1	0.31	1.743
9	150	0.2	0.2	0.55	1.405
10	200	0.05	0.05	0.06	2.671
11	200	0.05	0.1	0.20	0.819
12	200	0.05	0.2	0.23	1.153
13	200	0.1	0.05	0.08	0.567
14	200	0.1	0.1	0.07	1.857
15	200	0.1	0.2	0.44	1.165
16	200	0.2	0.05	0.24	1.543
17	200	0.2	0.1	0.03	1.382
18	200	0.2	0.2	0.28	1.463
19	250	0.05	0.05	0.04	0.924
20	250	0.05	0.1	0.08	0.945
21	250	0.05	0.2	0.30	0.793
22	250	0.1	0.05	0.12	0.598
23	250	0.1	0.1	0.12	0.856
24	250	0.1	0.2	0.14	0.675
25	250	0.2	0.05	0.19	1.584
26	250	0.2	0.1	0.08	1.724
27	250	0.2	0.2	0.09	1.634

Tool wear and surface roughness are measured for all 27 experiments. Results obtained are studied using graphs. The results are analyzed with analysis of variance (ANOVA), which helps in identifying the factors significantly affecting the performance measures.

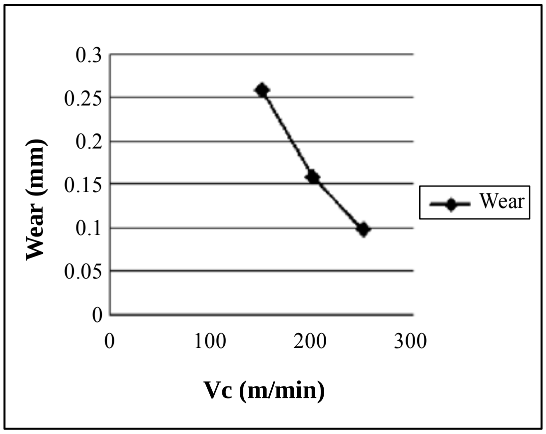


Fig. 7: Plots for cutting vs wear

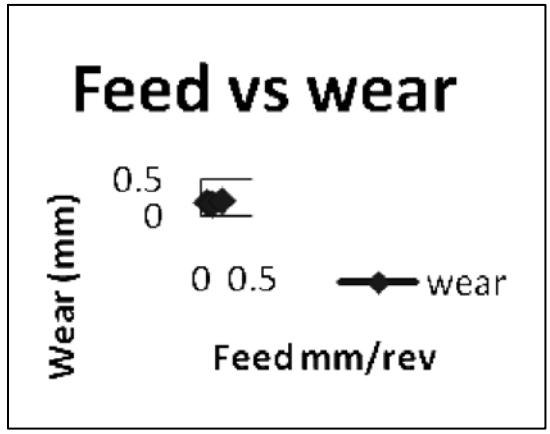


Fig. 8: Plots for feed vs wear

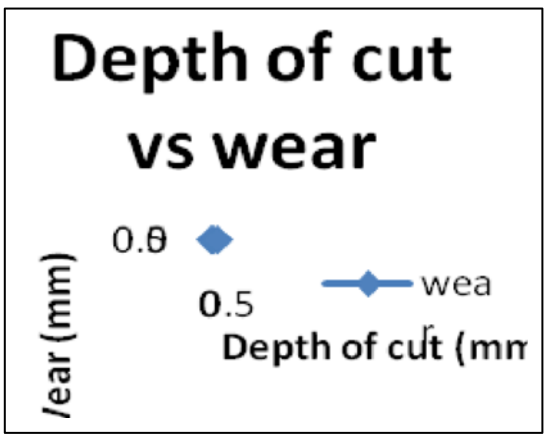


Fig. 9: Plots for depth of cut vs wear

From Fig. 7 it can be inferred that with a increase in cutting speed, wear decreases at a constant rate. This contradicts with the statement that flank wear increases with increasing cutting speed. It has been noted that chipping was observed on the flank of the tool rather than abrasive wear. The reason is high degree of brittleness of ceramic tools. At high cutting speed the built up edge formation is suppressed whereas at decreasing cutting speed built up educe formation is enhanced, which results in chipping and fracture. To minimize tool wear cutting speed of 250 m/min was suggested. There is slight reduction in amount of wear at a feed rate of 0.05 mm to 0.1 mm, but with increase in feed of 0.2 mm the amount of wear increases as shown in Fig 8. As the contribution of feed on flank wear is very low (1.58%) from the results of ANOVA as shown in table IV, the study on the effects.

Table 4: ANOVA Table for flank wear

Source of variance	Df	SS	Variance	F-value	P-value	C(%)
A(V,m/min)	2	0.12616	0.0631	3.27	0.068	31.72
B(F, mm/rev)	2	0.00642	0.0032	0.31	0.713	1.58
C(D, mm)	2	0.00642	0.0377	2.69	0.244	19.42
AB	4	0.05454	0.0111	0.84	0.493	9.71
AC	4	0.03706	0.0068	0.55	0.672	7.67
BC	4	0.03122	0.0028	0.29	0.940	1.62
Error	8	0.14113	0.0151			28.30
Total	26	0.40295				100

Table 5: ANOVA table for the surface roughness

Source of variance	Df	SS	Variance	F-value	P-value	C(%)
A(V,m/min)	2	0.7635	0.3690	2.63	0.156	9.82
B(F,mm/rev)	2	0.6643	0.3683	2.31	0.182	7.65
C(D, mm)	2	0.4234	0.2340	1.82	0.329	5.38
AB	4	2.1985	0.5624	3.16	0.066	27.13
AC	4	0.6345	0.1336	1.09	0.450	7.34
BC	4	1.8234	0.5515	2.98	0.098	24.23
Error	8	1.2654	0.1292			17.46
Total	26	7.7730				100

Df: Degrees of freedom SS: sum of squares C: Percent contribution of feed on wear is not of much importance. From Fig. 9 it is inferred that tool wear is an increasing function of depth of cut.

Table 6: Failure mode and effect analysis

S. No.	Problem	Effect	Severity	Occurrence	Detection	RPN
1	Improper surface finish	Variation in tolerance and degradation of standards	4	8	6	192
2	Breakage	Reduction in tool life	8	6	7	336
3	Chattering	Deviation in tolerance limits	6	3	5	90
4	Chipping	Too much wear	5	3	9	135
5	Wear	Change in dimension	6	4	5	120
6	Chip packing	Tool wear and improper finishing	7	8	6	336
7	Burr	Too much wear	5	6	3	90
8	Short tool life	High cost	4	5	6	120

For minimising tool wear depth of cut of 0.1 mm or 0.05 mm should be suggested. The significant factor influencing the tool wear is cutting speed, it explains 31.72% of the total variation as shown in Table 4.

The axial depth of cut has a influence physically explaining 19.42% of the total variation. The feed rate and other interactions have lower levels of contribution.

From Table 5 the interactions cutting speed-feed, feed-depth of cut have a statistically significant effect on surface roughness. From Fig. 9: feed-depth of cut interaction plot, the lowest levels of surface roughness is achieved at depth of cut of 0.05 mm and feed of 0.10 mm/tooth. The interaction plot of cutting speed and feed as shown in Fig. 10 reveals that the lowest levels of surface roughness is achieved at cutting speed of 250 m/min and feed rate of 0.10 mm/tooth or 0.05 mm/tooth. Therefore the optimal cutting conditions for machining are cutting speed of 250 m/min, feed of 0.10 mm/tooth, depth of cut of 0.05 mm.

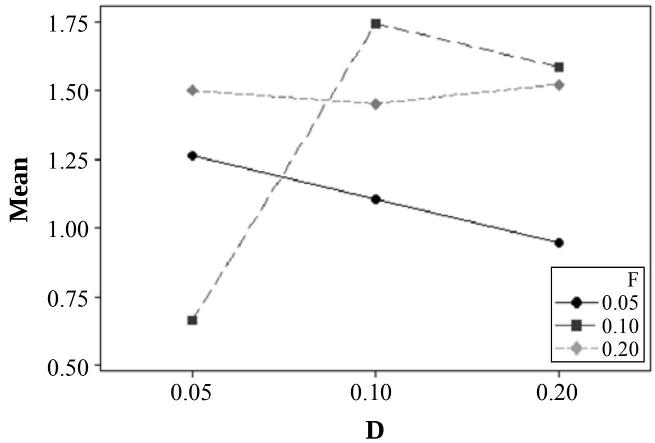


Fig. 9: Interaction plot b/w feed and depth of cut

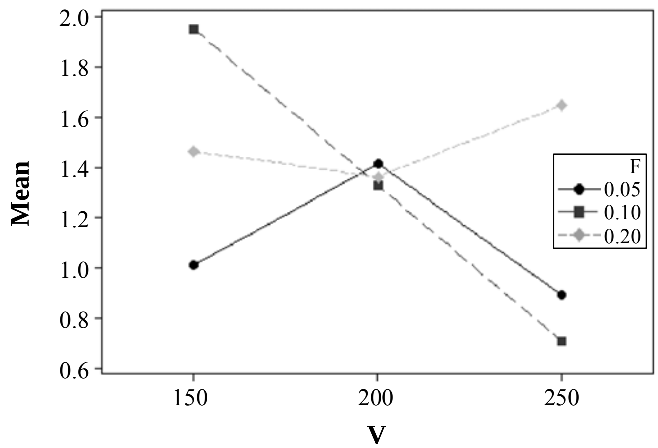


Fig. 10: Interaction plot b/w feed and cutting speed

Failure mode and effect analysis

In FMEA, failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. FMEA begins during the earliest conceptual stages of design and continues throughout the life of the product or service. FMEA helps select remedial actions that reduce cumulative impacts of life-cycle consequences (risks) from a systems failure (fault). Failure mode and effect analysis has been established for end milling operation as shown in the Table 6.

The failure modes are categorized based on the risk priority numbers by multiplying ratings of occurrence, severity and detection. Of all the failure modes listed chip packing was found to have highest risk priority number of 336. The causes for the failure was found to be too great cutting depth, not enough coolant and not providing room for chips. The effects observed while chip packing are tool wear, improper finishing and poor chip dispersion. In order to avoid chip dispersion, feed and speed can be adjusted accordingly. By proper selection of number of flutes in the cutter, tool wear can be reduced. Surface finish can be enhanced by supplying more coolant.

CONCLUSION

Initially various cutting tools used in precision machining centre are observed for failure and it is found out that 34.6% of failure is observed in ø 12 chatter free end mill cutter. About 36.4% of ø 12 chatter free end mill cutters are failed due to wear and about 27.3% of ø 12 chatter free end mill cutter are subjected to total breakage. Therefore failure analysis for wear and total breakage has been conducted on ø 12 chatter free end mill cutter. The results of the experiments are listed below.

- Cutting speed and depth of cut are the most influential factors for flank wear whereas the interactions cutting speed-feed, feed-depth of cut have a statistically significant effect on surface roughness.
- The optimum cutting parameters for tool wear reduction are cutting speed of 250 m/min, feed rate of 0.1 mm/rev and depth of cut of 0.05 mm or 0.1 mm
- The optimum cutting conditions for better surface roughness are cutting speed of 250 m/min, feed of 0.10 mm/tooth and depth of cut of 0.05 mm.
- Chip packing was found to have highest risk priority number among all the failures observed. The causes for chip packing are found to be, too great cutting depth and not providing enough chip room. This can be overcome by adjusting the feed or speed, by using less number of flutes in end mill cutter and but providing more coolant.

REFERENCES

1. V. Kumar, A. Eakambaram and A. Arivazhagan, FEM Analysis to Optimally Design End Mill Cutters for Milling of Ti-6Al-4 V, Procedia Engg., **97**, 1237-1246 (2014).
2. S. P. Kumar, R. Venkatakrishnan and S. Vignesh Babu, Process Failure Mode and Effect Analysis on end Milling Process- A Critical Study, IJMET, **4(5)**, 191-199 (2013).

3. M. Zetek, I. Cesakova and V. Svarc, Increasing Cutting Tool Life when Machining Inconel 718, Procedia Engg., **69**, 1115-1124 (2014).

4. J. Paulo Davim and L. Figueira, Machinability Evaluation in Hard Turning of Cold Work Tool Steel (D2) with Ceramic Tools using Statistical Techniques, Mater. Design, **28**, 1186-1191 (2007).

5. Vikas B. Magdum and Vinayak R. Naik, Evaluation and Optimization of Machining Parameter for Turning of EN 8 Steel, IJETT, **4(5)** (2013).

6. B. M. Gopalasamy, B. Mondal and S. Ghosh, Taguchi Method and ANOVA: An Approach for Process Parameters Optimization of Hard Machining While Machining Hardened Steel, JSIR, **68**, 686-695 (2009).

7. S. Hasan, S. Thamizhmanii and S. Saparudin, Analyses of Surface Roughness by Turning Process using Taguchi Method, JAMME 20 (2007).

8. R. K. Suresh, G. Krishnaiah, V. Diwakar Reddy and T. Sreenivasa Murthy, Optimization of Process Parameters in Dry Turning Operation of EN 41B Alloy Steels with Cermet Tool Based on the Taguchi Method, IJERA, 1144-1148 (2013).

9. A. R. Motorcu, The Optimization of Machinining Parameters using the Taguchi Mechod for Surface Roughness of AISI 8660 Hardened Alloy Steel, J. Mechanical Engg., **56**, 391-401 (2010).

Accepted : 20.05.2016